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# INDEX TO BENET LABORATORIES TECHNICAL REPORTS - 1997

R. D. NEIFELD

APRIL 1998

US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
CLOSE COMBAT ARMAMENTS CENTER
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**13. ABSTRACT** (Maximum 200 words)

This paper describes the design and operation of an experimental hybrid cannon consisting of a 60-mm bore gas cannon using standard propellant and a traveling-wave induction accelerator. The projectile, consisting of an aluminum cylinder weighing 120 grams, is initially brought up to a speed of 600 m/s in the gas cannon. The pulsed-power stage is designed to accelerate the projectile further to a velocity of 700 m/s.

**14. SUBJECT TERMS**
Hybrid Cannon, Hybrid Launcher, Chemical/EM Launcher, Electromagnetic Accelerator, Electromagnetic Launcher

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ELECTRON TRANSPORT IN HIGHLY TEXTURED METAL FILMS GROWN BY PARTIALLY IONIZED BEAM DEPOSITION

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**6. AUTHOR(S)**
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**13. ABSTRACT** (Maximum 200 words)

In principle, the resistivity of bulk face-centered-cubic (fcc) materials should not depend on the orientation due to the fact that the conductivity tensor is single valued. However, we show that this conclusion is not valid for thin films. Deposition of highly oriented aluminum, silver, and copper films on amorphous substrates using the partially ionized beam (PIB) technique exhibits a resistivity that is strongly correlated with the texture, i.e., the tighter the texture, the lower the film resistivity. We model the film as an array of grains whose grain boundaries can be considered as delta function potentials for electron scattering, and the strength of the potentials can be calculated from the measured resistivity of the films. On the other hand, the fiber texture distribution of the films is obtained from X-ray pole figure measurements, and Monte-Carlo simulations are then performed using these data to determine the average dislocation density at the grain boundaries due to the grain-to-grain crystallographic mismatch. We show that the transmittance coefficient for electron scattering, and therefore, the film resistivity, is a monotonically increasing function of the average dislocation density. We, therefore, conclude that the structure of grain boundaries in a thin film provides the necessary mechanism by which the resistivity of an fcc cubic metal can depend on the texture.

**14. SUBJECT TERMS**
Partially Ionized Beam Deposition, Aluminum Films, Silver Films, Copper Films, Resistivity, Monte-Carlo Simulation, Electron Transport

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**13. ABSTRACT** (Maximum 200 words)

A fatigue study was conducted to evaluate wire electrical discharge machining (EDM) as a manufacturing method for the production of the intricate lug geometry on multi-lug breech mechanisms. The wire EDM process produces a thin surface layer of recast material that was found to have an adverse effect on specimen fatigue life. Removal of the recast layer is recommended on highly stressed critical components.

Unidirectional bending fatigue tests were performed utilizing notched rectangular test specimens made from ASTM A723 steel material. The fatigue tests compared wire EDM prepared surfaces to those produced by the conventional drilling and honing process. The effects of multiple EDM passes and post-processing techniques such as bead blast cleaning, shot peening, and mechanical overloading were investigated.

The recast layer was found to have a significant detrimental effect on specimen fatigue lives. Fatigue life reductions of 20 to 40 percent were observed. The deleterious effect on fatigue increases as the applied stress decreases. The post-processing techniques improved lives but they were generally inferior to those,that were conventionally machined and treated with the same process. In limited testing, the combination of glass bead cleaning and mechanical overloading provided "significant" improvement in life compared to either process applied individually.

**14. SUBJECT TERMS**
EDM Recast Layer, Fatigue, Glass Bead Clean, Gun Steel, Multi-Lug Breech Mechanisms, Overload, Shot Peen, Wire EDM

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STRESS CONCENTRATION, STRESS INTENSITY, AND FATIGUE LIFETIME CALCULATIONS IN AUTOFRETTAGED TUBES CONTAINING AXIAL PERFORATIONS WITHIN THE WALL

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**13. ABSTRACT** (Maximum 200 words)

Elastic, elastic-plastic, and experimental stress analyses and fatigue lifetime predictions are presented for thick cylinders containing multiple, axial holes within the wall. The holes are generally semi-elliptical (including semi-circular) and the cylinders are autofrettaged after introduction of the holes and are subsequently subjected to cyclic pressurization of the bore.

Two potentially critical failure locations are identified; a fracture-mechanics based design methodology is proposed; elastic and elastic-plastic finite element (FE) analyses are undertaken. The elastic FE analysis predicts hoop stresses at the bore resulting from internal pressurization which are some 7% higher than those for the equivalent plain tube. For a given hole size and location and for nominal overstrains of 40% or greater, the residual compressive stress at the bore is reduced by approximately 15% below the value for a plain tube of the same radius ratio.

Two experimental investigations are reported, one based upon X-ray diffraction, to measure residual stresses, and the other based upon radial tube slitting, to measure opening angle. They confirm most features of the residual stress profiles predicted from FE analysis, with the exception of high compressive residual stresses and stress gradients immediately adjacent to the hole boundaries. Appropriate use of the residual stress information permits prediction of tube lifetimes for cracks emanating from the bore and from the hole. For the geometry and loading under consideration, the more critical location is predicted to be the hole boundary, the lifetime for failures originating from this point being some 60% of the lifetime for cracks originating at the bore.

**14. SUBJECT TERMS**
Autofrettage, Crack Growth, Fatigue Cracks, Cylinders, Channels, Fracture (Materials), Fracture Mechanics, Residual Stress, Stress Concentration Factor, Stress Intensity Factor

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THERMOCHEMICAL EROSION MODELING
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Stuart Dunn*, and Douglas Coats*
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**13. ABSTRACT** (Maximum 200 words)

The MACE gun barrel thermochemical erosion modeling code addresses wall degradations due to transformations, chemical reactions, and cracking coupled with pure mechanical erosion for the original M242/M919 gun system. This predictive tool provides gun system design information that is otherwise impractical. The A723, 0.002-inch plated chromium/A723, and 0.002-inch sputtered tantalum/A723 wall materials are evaluated for erosion using the M242 Cycle A firing scenario. This complex computer analysis is based on rigorously evaluated scientific theory that has been validated in the rocket community over the last forty years. Our gun erosion analysis includes the standard interior ballistics gun code (XNOVAKTC), the standard nonideal gas-wall thermochemical rocket code modified for guns (CCET), the standard mass addition boundary layer rocket code modified for guns (MABL), and the standard wall material ablation conduction erosion rocket code modified for guns (MACE). This analysis provides wall material erosion predictions and comparisons (ablation, conduction, and erosion profiles) as a function of time, travel (customer-selected 6-inch, 12-inch, 30-inch), and number of rounds to barrel condemnation. These original M242/M919 gun system predictions agree well with the standard wall heat transfer/temperature profile code (FDHEAT) and actual measured gun system erosion data.

**14. SUBJECT TERMS**
Modeling Code, Thermochemical Erosion, Erosion Predictions, Gun Barrels, Thermochemical Ablation, Mechanical Erosion, M242/M919 Gun System, Chromium, Tantalum

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This paper presents an applied method for the optimal design of passive vibration absorbers to reduce terrain-induced vibrations of tank cannons. The method uses a finite element model of the cannon, which was formulated using the Euler-Bernoulli transverse beam approximation. This model is then transformed to the Laplace "*s*" domain (transfer function form) using the MATLAB® software package. The design is optimized by assigning a scalar cost function to the frequency response of the modified barrel, which provides a metric for minimizing the design parameter space. The results indicate that the peak amplitude of the frequency response of a 1,500 Kg barrel may be cut in half by an appropriately tuned 20 Kg absorber located at the muzzle. Also, sensitivity of the design to parametric variation and modeling uncertainty is significantly reduced with Rayleigh stiffness proportional damping of the absorber in the range 0.02 $\frac{\text{N/(m/s)}}{\text{N/m}}$.

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FATIGUE ANALYSIS OF A VESSEL
EXPERIENCING PRESSURE OSCILLATIONS

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**6. AUTHOR(S)**

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**13. ABSTRACT** (Maximum 200 words)

A pressure vessel, which was designed and tested under laboratory conditions for tens of thousands of cycles, failed in service after only a few cycles. Thousands of oscillatory pressure reversals were measured at each loading. However, the predominance of the stress amplitudes were well below the critical threshold values necessary to initiate fatigue cracking.

Analysis demonstrated that the disparity between lab cycling and field loading conditions could not be explained simply by mechanical loading alone. Further investigation into the problem revealed that an extremely aggressive environment, the by-products of the internal combustion from within the pressure vessel, along with high temperatures, pressures, and other sources of high tensile loading all contributed to the short fatigue life of the vessel.

**14. SUBJECT TERMS**
Low-Cycle Fatigue, Pressure Oscillations, Pressure Vessels, Cumulative Damage Model, Residual Stresses, Hoop Stress, Radial Stress, Fatigue Cracks, Palmgren-Miner Rule, Environmentally-Assisted Cracking

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**4. TITLE AND SUBTITLE**
HYDROGEN-INDUCED CRACKING TESTS OF HIGH-STRENGTH STEELS AND NICKEL-IRON BASE ALLOYS USING THE BOLT-LOADED SPECIMEN

**5. FUNDING NUMBERS**
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**6. AUTHOR(S)**

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**13. ABSTRACT** (Maximum 200 words)

Hydrogen-induced cracking tests were conducted on high-strength steels and nickel-iron base alloys using the constant displacement bolt-loaded compact specimen. The bolt-loaded specimen was subjected to both acid and electrochemical cell environments to produce hydrogen. The materials tested were A723, Maraging 200, PH 13-8 Mo, Alloy 718, Alloy 706, and A286, ranging in yield strength from 760-1400 MPa. The effects of chemical composition, refinement, heat treatment, and strength on hydrogen-induced crack growth rates and thresholds were examined. In general, all high strength steels tested exhibited similar crack growth rates and threshold levels. In comparison, the nickel-iron base alloys tested exhibited crack growth rates up to three orders of magnitude lower than the high-strength steels tested. It is widely known that high-strength steels and nickel base alloys exhibit different crack growth rates, in part, because of their different crystal cell structure. In the high-strength steels tested, refinement and heat treatment had some effect on hydrogen-induced cracking, although strength was the predominant factor influencing susceptibility to cracking. When the yield strength of one of the high-strength steels tested was increased moderately, from 1130 MPa to 1275 MPa, the incubation times decreased by over two orders of magnitude, the crack growth rates increased by an order of magnitude, and the threshold stress intensity was slightly lower.

**14. SUBJECT TERMS**
Threshold Stress Intensity, Hydrogen-Induced Cracking, Hydrogen Cracking, Hydrogen Embrittlement, Environmental Fracture, Environmental Cracking, Crack Growth Rates, High-Strength Steels, Nickel-Iron Base Alloys

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**4. TITLE AND SUBTITLE**
AMBIENT TEMPERATURE TESTING OF METALLIC MATERIALS EXPOSED TO PROPELLANT COMBUSTION ENVIRONMENTS CONTAINING HYDROGEN

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**6. AUTHOR(S)**
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**13. ABSTRACT** (Maximum 200 words)

Combustion gases containing hydrogen can cause severe environmental degradation and cracking in the high strength steels used in gun tubes. Although the hydrogen is evolved at the elevated temperatures of combustion, the deleterious effects of hydrogen on steel are most severe near ambient temperature.

**14. SUBJECT TERMS**
Environmentally-Assisted Cracking, Hydrogen-Induced Cracking, Hydrogen Embrittlement, Propellants, Combustion Gases, High Strength Steels

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SCALING ANALYSIS OF THERMOGRAPHIC IMAGES USING NEURAL NETWORKS

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**6. AUTHOR(S)**
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**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
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**13. ABSTRACT** (Maximum 200 words)

Sequences of thermographic images of burning residue produced by M198 155 (unicharge) test rounds fired at Yuma Proving Ground (YPG) were collected for analysis to elucidate the evolution of conditions in the breech after firing and to provide guidance in determining safe loading protocols for future autoloaders. In order to better understand the thermal environment in the breech, we are developing advanced analytical tools that can be used to quantitatively characterize sequences of thermographic images. However, for this study the calibration data required to extract the temperature profiles the YPG thermographic images for these analyses was unavailable. No analytic solution could be determined to perform the highly nonlinear reverse transformation from RGB space to intensities; therefore, a neural network was employed. Furthermore, the experimental data provided by YPG were only measurable over a restricted range of temperatures extending from approximately 80°C up to 110°C. Since the highest temperatures measured in the thermographic data did not correspond to a hazardous condition, more complex measures than simple statistical averages of the temperature had to be used. A new numerical technique represented by sparse data sets was introduced for measuring the scaling properties of single-valued surfaces in 3-space.

**14. SUBJECT TERMS**
Neural Networks, Scaling Analysis, Parallel Processing, Image Processing, Fractal Analysis

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**4. TITLE AND SUBTITLE**
EROSION MODELING OF THE
120-MM M256/M829A2 GUN SYSTEM

**5. FUNDING NUMBERS**
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**6. AUTHOR(S)**
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Published in proceedings of the conference.

**12a. DISTRIBUTION / AVAILABILITY STATEMENT**
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**13. ABSTRACT** (Maximum 200 words)

The Benet Laboratories/Software and Engineering Associates, Inc. (SEA) gun barrel erosion modeling and design code predicts wall degradation due to transformations, chemical reactions, and cracking coupled with pure mechanical erosion for the 120-mm M256/M829A2 gun system for ambient temperature-conditioned rounds. The A723 steel and 0.005-inch high contraction (HC) chromium plated/A723 steel wall materials are evaluated for erosion. This complex computer analysis is based on rigorously evaluated scientific theory that has been validated in the rocket community over the last forty years. Our gun erosion analysis includes the standard interior ballistics gun code (XNOVAKTC), the standard nonideal gas-wall thermochemical rocket code modified for guns (CCET), the standard mass addition boundary layer rocket code modified for guns (MABL), and the standard wall material ablation conduction erosion rocket code modified for guns (MACE). In addition, bore subsurface metallographic analysis and projectile-bore finite element analysis (ABAQUS) are considered. Our overall analysis provides wall material erosion predictions and comparisons of ablation, conduction, and erosion profiles as a function of time, travel (customer-selected 27, 61, 86, 130, and 201 inches from the rear face of the tube), and number of rounds to barrel condemnation. The 120-mm M256/M829A2 gun system prediction, with significant numbers of M829A2 rounds, agrees well with the wear and erosion pattern of retired M256 gun barrels.

| 14. SUBJECT TERMS | 15. NUMBER OF PAGES |
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| Erosion Modeling, 120-mm M256/M829A2 Gun System,<br>Gun Barrels, Chromium, Steel | 24 |
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GUN BARREL VIBRATION ABSORBER

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**6. AUTHOR(S)**
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**13. ABSTRACT** (Maximum 200 words)

This paper presents an applied method for the optimal design of passive vibration absorbers to reduce terrain-induced vibrations of tank cannons. The method uses a finite element model of the cannon. The design is optimized by assigning a scalar cost function to the frequency response of the modified barrel. The results indicate that the peak amplitude of the frequency response of a 1,500 Kg barrel may be cut in half by an appropriately tuned 20 Kg absorber. Experimental validation of the results using modal impact testing are shown.

**14. SUBJECT TERMS**
Vibration Absorbers, Passive, Design, Cannons,
Gun Barrels, Finite Element Method

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**4. TITLE AND SUBTITLE**
LABORATORY CHARACTERIZATION OF PROTOTYPE CRUSADER 155-MM XM297 TEST CANNON #1

**5. FUNDING NUMBERS**
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**6. AUTHOR(S)**
Michael J. Audino, John H. Underwood, Edward J. Hyland, James A. Neese, Daniel J. Corrigan, and Kenneth D. Olsen

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
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**13. ABSTRACT** *(Maximum 200 words)*

During the design and development of weapon systems, it is imperative to evaluate prototype components for the purpose of validating theoretical calculations and predictions made earlier in the design process. This report describes strain characterization testing conducted on 155-mm XM297 Test Cannon #1 for the purpose of validating calculated strains from the swage autofrettage process, evaluating fatigue life of various midwall and outer wall geometric configurations, validating calculated strains from simulated service life conditions, determining the maximum pressure containment capability of the cannon, and finally, determining the failure mode of the cannon.

**14. SUBJECT TERMS**
Characterization, Autofrettage, Midwall, Service Life Conditions, Failure Mode, Pressure Amplitude, Safe Maximum Pressure, Burst Test, Coolant Groove, International Test Operating Procedures

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**6. AUTHOR(S)**
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**13. ABSTRACT** (Maximum 200 words)

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FATIGUE RECLAMATION: THE CONCEPT OF SELF-HEALING

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**6. AUTHOR(S)**
E. Troiano, P.J. Cote, and G.N. Vigilante

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
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**13. ABSTRACT** (Maximum 200 words)

A simple analytical model for predicting the onset of fatigue crack initiation has been developed. The model's usefulness is based on the premise that if a component can be removed from service before fatigue crack initiation and thermally heat-treated to remove any accumulated fatigue damage, it can be placed back in service and periodically heat-treated to extend its life.

Three-point bend specimens with semi-circular notches were machined from A723 steel, isothermally processed in molten salts to predetermined strength and toughness levels, and fatigue-tested in the extreme low cycle fatigue region.

Because of negative preliminary findings, the concept of reclamation fatigue in the extremely low cycle fatigue regime does not appear to be a viable means for extending the overall life of components. Although technically correct, the model did not accurately predict the onset of crack initiation. The study also suggests that, although cracking was not observed in all specimens, some damage could not be eliminated by thermal treatment. Because most point defects will be eliminated by thermal treatment, it is believed that non-detectable microscopic crack growth had occurred.

| 14. SUBJECT TERMS | 15. NUMBER OF PAGES |
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MODIFICATION OF ASTM STANDARD E1681 ON ENVIRONMENTAL CRACKING TO INCLUDE BOLT-LOAD SPECIMEN TESTING

**5. FUNDING NUMBERS**
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**6. AUTHOR(S)**
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**13. ABSTRACT** (Maximum 200 words)

Benet Laboratories experience with environmental cracking of cannon components has been combined with the technical expertise of various participants at ASTM technical meetings and symposia to develop a modification to ASTM Standard E1681, "Test Method for Determining a Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials Under Constant Load." A bolt-loaded compact specimen has been added to the standard to allow constant displacement bolt-load tests of environmental cracking threshold.

Recent investigations of environmental cracking in two cannon systems are briefly summarized, including cracking in acids used in the electroplating process and cracking due to cannon propellant gases. The modified draft of ASTM Standard E1681 is presented, including the additions to test procedure, apparatus, and stress intensity factor expressions required to perform bolt-load tests of environmental cracking threshold.

**14. SUBJECT TERMS**
Environmental Cracking, Fracture Mechanics, High Strength Steels, Bolt-Load Specimen, Standardized Tests, Cracking Threshold

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**5. FUNDING NUMBERS**
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**6. AUTHOR(S)**
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Stuart Dunn*, and Douglas Coats*
* Software and Engineering Associates, Inc., Carson City, NV

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**13. ABSTRACT** (Maximum 200 words)

The MACE gun barrel thermochemical erosion modeling code addresses wall degradations due to transformations, chemical reactions, and cracking coupled with pure mechanical erosion for the 25-mm M242/M791 gun system. This predictive tool provides gun system design information that is otherwise impractical. The nitrided A723 and 0.002-inch plated chromium/A723 wall materials are evaluated for erosion using the M242 Cycle A firing scenario. This complex computer analysis is based on rigorously evaluated scientific theory that has been validated in the rocket community over the last forty years. Our gun erosion analysis includes the standard interior ballistics gun code (XNOVAKTC), the standard nonideal gas-wall thermochemical rocket code modified for guns (CCET), the standard mass addition boundary layer rocket code modified for guns (MABL), and the standard wall material ablation conduction erosion rocket code modified for guns (MACE). This analysis provides wall material erosion predictions and comparisons (ablation, conduction, and erosion profiles) as a function of time, travel (customer-selected 6-inch, 12-inch, 30-inch), and number of rounds to barrel condemnation. These M242/M791 gun system predictions agree well with the standard wall heat transfer/temperature profile code (FDHEAT) and actual measured gun system erosion data.

**14. SUBJECT TERMS**
Modeling Code, Thermochemical Erosion, Gun Barrels, 25-mm M242.M791 Gun System, Ablation, Conduction, Erosion, Chromium, A723 Steel

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**6. AUTHOR(S)**
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**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
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**13. ABSTRACT** (Maximum 200 words)

The buffer housing casting proved to be a very costly and difficult part to manufacture. The defect criteria were too restrictive and caused a high percentage of rejections. This dynamic measurements study showed some areas of the casting with low stresses. The defect criteria were modified to accept castings that original criteria would reject.

**14. SUBJECT TERMS**
Buffer Housing, Mortars, 120-mm Mortars, M120,
M121 Mortars, Castings, Defects

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RESIDUAL STRESS IN SWAGE AUTOFRETTAGED CYLINDERS WITH AXIAL SEMI-CIRCULAR MID-WALL COOLING CHANNELS

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**6. AUTHOR(S)**
S.L. Lee, J. Neese, and E. Hyland

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**13. ABSTRACT** (Maximum 200 words)

ABAQUS finite element modeling and experimental residual stress mapping have been performed for several swage autofrettaged compound cylinders with semi-circular mid-wall cooling channels. The experimental results verified most features of ABAQUS-predicted stress distributions, except near the bore and at the channel roots, where significantly reduced compressive residual stresses were observed. These observations have been attributed to reverse yielding effect in these areas.

**14. SUBJECT TERMS**
Autofrettage, Compound Cylinders, Perforated Cylinders, Residual Stress, Reverse Yielding, Bauschinger Effect

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**4. TITLE AND SUBTITLE**
INFLUENCE OF THE BAUSCHINGER EFFECT ON RESIDUAL STRESS AND FATIGUE LIFETIMES IN AUTOFRETTAGED THICK-WALLED CYLINDERS

**5. FUNDING NUMBERS**
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**6. AUTHOR(S)**
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**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
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**13. ABSTRACT** (Maximum 200 words)
This work addresses the influence of Bauschinger effect upon residual stresses and associated fatigue lifetimes for pressurized, autofrettaged thick cylinders. The model employed allows for the variation with radius of Bauschinger Effect Factor (BEF) throughout the autofrettaged tube since the percentage plastic strain, which determines BEF, will vary from a maximum value at the bore to zero at the elastic-plastic interface.

Accounting for BEF variability, it is demonstrated that the residual compressive hoop stress at the inner radius of the tube reaches a maximum value at the percentage overstrain level below which reversed yielding does not occur. Existing experimental residual stress measurements from a variety of sources are shown to support this thesis. This value of overstrain may serve to maximize crack initiation lifetime in autofrettaged thick cylinders.

For a tube with significant heat-checking and associated initial crack-like defects, it is necessary to consider fatigue crack growth rates governed by a crack growth law such as Paris's Law. For a tube of radius ratio 2.0 and at a value of approximately 40% overstrain, slightly in excess of that for the onset of reversed yielding, the fatigue lifetime exhibits a maximum value. Fatigue lifetimes achieve a maximum value at overstrain levels in which yielding reaches 1.4 times bore radius and are almost constant thereafter. Furthermore, such extended overstrain leads to a small increase in residual stress at the outside diameter (OD), thus increasing R ratio at that location and reducing fatigue lifetime for crack growth originating at the OD. Existing experimental lifetime measurements are shown to require the inclusion of BEF to properly account for these observed lifetimes.

**14. SUBJECT TERMS**
Bauschinger Effect, Crack Growth, Fatigue Cracks, Fatigue Lifetimes, Cylinders, Fracture (Materials), Fracture Mechanics, Residual Stress, Stress Intensity Factor

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HYDROGEN CRACKING DURING SERVICE OF HIGH STRENGTH STEEL CANNON COMPONENTS

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**6. AUTHOR(S)**
J.H. Underwood, E. Troiano, G.N. Vigilante, A.A. Kapusta, and S. Tauscher

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
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**13. ABSTRACT** (Maximum 200 words)

An investigation of environmental cracking during service of high strength steel cannon components is described. Two cases of cracking occurred in similar prototypes of an advanced cannon over a two-year period. The materials, components configurations, applied and residual stresses, environmental conditions, and the resulting cracking behaviors and SEM fracture surface characteristics are outlined. Laboratory hydrogen cracking tests of the cannon materials, finite element stress analysis, and stress intensity factor calculations were used to model the hydrogen cracking. The first cracking incident involved cracks up to 21-mm long near a pressure seal in an 1160 MPa yield strength ASTM A723 forged steel cannon tube, following five firing cycles. The second incident involved 50-mm long cracks that had grown after thirty firing cycles near the seal between two adjoining cannon components, one made from A723 and one from 1280 MPa yield strength PH 13-8 Mo stainless steel. The cause of cracking, given the presence of hydrogen-laden propellant products and susceptible high strength steels, was the sustained tensile stresses arising from assembly preloads required to maintain pressure seals between cannon components. Recommended preventative measures include reducing the strength level of the existing martensite steels, changing to austenitic nickel-iron base alloys, and redesign to lower the level of sustained tensile stress concentrations in areas subjected to propellant environments.

| 14. SUBJECT TERMS | 15. NUMBER OF PAGES |
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**6. AUTHOR(S)**
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**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

This report documents the performance of the dynamically tuned shroud vibration absorber—which was designed and constructed at Benet Laboratories—during bump-course testing on a modified M1A1 tank at Aberdeen Proving Ground on 7 March 1997. The dynamically tuned shroud reduces the receptance of the gun barrel to vibrational energy while the tank traverses rough terrain. It is anticipated that this will enhance the accuracy of the weapon system by reducing variation in the initial conditions of gun barrel flexure at the start of launch dynamics. The test results demonstrated that one of the three configurations tested reduced vertical flexure by 24% overall, with a factor of four reduction in the power spectrum amplitude of the first bending mode. Thus, the testing demonstrated that a simple passive approach using existing hardware can significantly enhance the dynamic performance of a weapon system.

| 14. SUBJECT TERMS | 15. NUMBER OF PAGES |
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**4. TITLE AND SUBTITLE**

MODAL ANALYSIS OF MORTAR BASEPLATES

**5. FUNDING NUMBERS**

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**6. AUTHOR(S)**

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Elwood Eisler (Union College), and Carlos I. Gutierrez

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

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**12b. DISTRIBUTION CODE**

**13. ABSTRACT** (Maximum 200 words)

The dynamic behavior of mortar baseplates due to shock loading, especially in large caliber mortars, has traditionally led to a number of conjectures among the community of ordnance engineers regarding baseplate structural failure modes such as cracking, gross plastic distortion, etc. Strain field measurements indicate that stress is high with considerable vibration activity of an offensive nature. These events have led to analytical investigations of mortar baseplates using finite element analysis (FEA), with most of these analyses predicting large deformation gradients that have motivated concerns on vibration levels.

The manufacture of some baseplates, notably the 120-mm mortar baseplate, is quite laborious. This type of baseplate consists of a monocoque weldment that has more than 64 parts jointed by no less than 100 feet of weld-joints. It follows then that it would be highly advantageous to have simple dynamic acceptance criteria for these baseplates in terms of simple bench instrumented "ringing check-out tests."

The purpose of this investigation was to determine and describe the dynamic behavior of the 120-mm mortar baseplate through the use of experimental modal analysis. The information may be used to validate advanced FEA theoretical models relative to the dynamic behavior of these type of structures. The information also may be utilized as a baseline for developing the aforementioned manufacturing "ringing" acceptance criteria for assessing mortar baseplate quality, notably the presence of undesirable defects such as gaps, poor weldments, etc. Our investigation includes the results of more than 200 individual measurements from the structure. The results are presented in computer animation format, as well as the traditional graphical and tabular formats. Finally, the experimental results are compared to theoretical predictions of simplified FEA.

**14. SUBJECT TERMS**

Modal Analysis, Mortar Baseplates, Vibration of Shells, Fast Fourier Transform Analysis, Computer Animation of Modal Analysis, Experimental Modal Analysis of Shells

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**13. ABSTRACT** *(Maximum 200 words)*

If a projectile is loaded into a hot cannon tube, the heat from the cannon starts to raise the temperature of the seated round. If not fired quickly (as in a misfire, checkfire, or hangfire situation), the projectile temperatures may increase to a critical point where the high explosive (HE) filler will start to melt, expand, and chemically separate in a process called "exudation." When this occurs, the melted filler becomes more sensitive to detonation, and the rapidly increasing volume of the HE can force the liquid filler out of the fuze threads onto the bore of the hot tube. In the latter event, the probability of an inbore detonation increases dramatically with the possibility of injury to the crew and damage to the cannon platform. This report documents the results of an experiment in which two common 155-mm HE projectiles (the M107 and the rocket-assisted M549A1) were preconditioned to an initial temperature, then rammed into a tube (which itself was preconditioned to a different initial temperature). Time-temperature data for both the projectiles and the tube were gathered, and the reduced data are presented herein.

**14. SUBJECT TERMS**
Cannon, Cannon Tubes, Projectile, 155-mm M549A1 Projectile, 155-mm M107 Projectile, 155-mm M284 Cannon, High Explosive, Exudation, Thermal Effects

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MODELING OF EROSIVE COMBUSTION PRODUCTS AFFECTING THE 120-MM M256/M829A2 GUN SYSTEM

**5. FUNDING NUMBERS**

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**6. AUTHOR(S)**

Samuel Sopok and Peter O'Hara

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

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**13. ABSTRACT** (Maximum 200 words)

The MACE gun barrel erosion code is used to thermochemically model erosive combustion products affecting the 0.005-inch high contraction (HC) chromium plated A723 steel 120-mm M256/ambient temperature-conditioned M829A2 gun system for a single-round firing scenario. The HC chromium plate, the subsurface A723 steel substrate at HC chromium crack bases, and bare A723 steel are evaluated. This gun erosion analysis includes the standard interior ballistics gun code (XNOVAKTC), the standard nonideal gas-wall thermochemical rocket code modified for guns (CCET), the standard mass addition boundary layer rocket code modified for guns (MABL), and the standard wall material ablation conduction code modified for guns (MACE). Specifically, this new variation of the gun erosion analysis uses MACE wall temperatures as a function of time/position/depth, as well as their associated gas pressures as a function of time/position to thermochemically compute differences in combustion products for the various reacting and nonreacting walls allowing erosive combustion products to be identified. Identification of erosive combustion products by comparative modeling between proposed and present propellant formulations or between a propellant formulation with and without additives may benefit current U.S. Army/Navy programs that attempt to lower propellant flame temperature and/or propellant erosion. Carbon dioxide, water, and carbon monoxide are the identified erosive combustion products for this gun system.

**14. SUBJECT TERMS**

Gun Erosion Modeling, Erosive Combustion Products, 120-mm M256 Barrels, M829A2 Rounds

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